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ABSTRACT

Inference is discussed as a factor in the derivation of non-explicit antecedents and referents for three types of discourse anaphora: definite pronouns, "one"-anaphora, and verb phrase ellipsis. This derivation process is seen as being part of the normal process of text-understanding. It is claimed that the use of non-explicit antecedents and referents for anaphora depends on a contract between speaker and listener. This contract requires that if the speaker uses an anaphoric expression whose antecedent or referent was inferentially derived, the listener both can and will make the same inference. Insofar as it is shown that many of these inferences rely on one of the few things explicitly available to both speaker and listener alike--i.e., the form of the utterance--the identification of a sentence's formal properties become a matter of cognitive concern. (Author)

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INFERENCE IN AN APPROACH TO DISCOURSE ANAPHORA

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1. Introduction

If one considers the question of what is accessible to anaphoric reference in English, one soon finds that none of the simple answers - text strings, pieces of syntactic structure, constituents of logical form - is adequate. The following examples should provide sufficient grounds for this claim. For each underlined anaphoric expression, the intuitively correct antecedent is just as intuitively neither a substring nor a constituent of a syntactic or "logical form" representation of the sentence.

(1) Wendy is going to Spain and Bruce is going to Crete, but in neither case do I know why **Ø**.
Ø = that person is going where s/he is going

(2) Irv and Martha wanted to dance together, but Martha's mother said that she couldn't **Ø**.
Ø = dance with Irv

(3) Each 3rd-grade girl brought Wendy a brick. On a dare, she stacked **them** into a 10-foot high wall.
them = the set of bricks, each of which some 3rd-grade girl brought to Wendy

(4) Blend a cup of flour with some butter. Moisten **it** with some milk, then knead it into a ball.
it = the flour-butter mixture.

(5) Whether Bruce buys a used car or a moped, his brother will want to borrow **it**.
it = the used car Bruce will have brought if Bruce buys a used car or the moped Bruce will have bought otherwise

(6) I have a '71 Ch. Figeac, a '76 Fleurie, a '71 Ockfener Bockstein and a '75 Durkheimer Feuerberg in the cellar. Shall we have the German **ones** for dinner tonight?
ones = wines

(Notice that these examples span a variety of anaphoric processes: sluicing (example 1), verb phrase ellipsis (example 2), definite pronoun anaphora (examples 3-5) and "one"-anaphora (example 6). Thus it should be clear that the existence of non-explicit antecedents is not an isolated phenomenon.)

No: one way of accounting for the existence of non-explicit antecedents in discourse is to say that "inference" is responsible. However as it is obvious that the discourse does not tell the listener explicitly what inferences to make, then one must still explain the fact that to a remarkable degree, both speaker and listener are reasoning in similar ways. This raises the following two questions:

1. What is it that guarantees similar reasoning on the part of both discourse participants?
2. Is there a limit to the kind of reasoning that the discourse participants might be willing to perform in order to derive antecedents?

My primary objective in this paper is to respond to the first question. In doing so, I shall characterize some very productive inferences which can account for many of the non-explicit antecedents of anaphoric expressions. While I shall not respond directly to the second question, my hope is that by identifying such inferences, it may become answerable as well.

In the first part of this paper I shall be discussing two types of "deep anaphora" (cf. Hankamer & Sag (1976)) - definite pronouns and "one"-anaphora - and in the second, a single type of "surface anaphora" - verb phrase ellipsis. I have made this division so as to provoke thinking about other types of "deep" anaphora - e.g., "do it" anaphora, "sentential it" anaphora - along the lines presented in the first part of the paper, and about other types of "surface" anaphora - e.g., sluicing, stripping, etc. - along the lines presented in the second. <*1>

2. Inference and Deep Anaphora

2.1 Discourse Models

One possible response to the question of what would guarantee similar reasoning on the part of both discourse participants is to invoke the notion of a **discourse model** - a concept frequently encountered in Artificial Intelligence literature on natural language understanding. This notion permits a clean account to be given of both the role of inference in text-understanding (Collins, Brown & Larkin, 1977) **and** of the items accessible to "deep"-anaphora.

Informally, a discourse model may be described as the set of entities "naturally evoked" by a discourse and linked together by

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<*1>. This paper is culled from the author's doctoral dissertation (Nash-Webber, 1978) to which interested readers are referred for further discussion.

the relations they participate in. These I will call **discourse entities.** (I can see no basic difference between what I am calling "discourse entities" and what Karttunen (1976) has called "discourse referents". My alternate terminology rests on wanting to keep "referent" a separate technical term.) The entities "naturally evoked" by the discourse may have the properties of individuals, sets, stuff, events, activities, etc.

In order to become familiar with the notion of entities "naturally evoked" by a discourse, consider the following sentence.

(7) Each 3rd-grade girl brought a brick to Wendy's house.

Then consider each continuation in (8a-e). In each case, I would label the referent of the definite pronoun (i.e., "she", "it" or "they") an entity "naturally evoked" by sentence (7).

(8)a. **She** certainly was surprised.
she = Wendy

b. **They** knew she would be surprised.
they = the set of 3rd-grade girls

c. She piled **them** on the front lawn.
them = the set of bricks, each of which some 3rd-grade girl brougnt to Wendy's house

d. She was surprised that they knew where **it** was.
it = Wendy's house

e. Needless to say, **it** surprised her.
it = the brick-presenting event

It is my assumption that one objective of discourse is to communicate a model: the speaker has a model of some situation which, for one reason or another, s/he wishes to communicate to a

listener. Thus the ensuing discourse is an attempt by the speaker to direct the listener in synthesizing a similar model.

Formally, a discourse model is a collection of entities, their properties and the relations they participate in. At any point in the discourse moreover, the discourse model validates the sequence of propositions embodied in the discourse up to that point. Now a speaker is usually not able to communicate at once all the relevant properties and relations associated with one of these discourse entities. That task requires multiple acts of reference. When the speaker wants to refer to an entity in his or her discourse model, s/he may do so with a definite pronoun. In so doing, the speaker assumes (1) that on the basis of the discourse thus far, a **similar** entity will be in the listener's (partially formed) model and (2) that the listener will be able to access and identify that entity via the minimal cues of pronominal reference. A definite pronoun then has a **referent**, which is an entity in the speaker's discourse model which s/he presumes to have a counterpart in the listener's discourse model.

Alternatively, the speaker may refer to a discourse entity by constructing a **description** of it in terms of some or all of its known properties and/or relations (e.g., "a red balloon", "Mary's mother", etc.). This may result in an entity being evoked into the listener's discourse model having at least the properties (or participating in the relations) mentioned in the given description. So while a discourse entity may be the **referent** of a

definite pronoun, the pronoun's **antecedent** will be that description conveyed by the immediately preceding text. The relationship between the discourse or the spatio-temporal context on the one hand, and the referents of definite pronouns on the other is thus an indirect one, mediated by the discourse participants' models. The discourse, in communicating property and relation information, serves as one possible source of antecedent descriptions and thus, indirectly, as one possible source of referents.

As for the role of "one"-anaphora (example (6)) in this scheme of things, I am assuming that a "one"-anaphor substitutes for a description. This description is in turn its **antecedent**. There are at least two possible reasons a speaker may have for using a "one"-anaphor in discourse: brevity and contrast. When a speaker builds a noun phrase around a "one"-anaphor, any additional modifiers in the noun phrase can serve to differentiate and contrast the current description with some set of alternatives which the speaker perceives or believes the listener to be aware of. Where the anaphor-containing noun phrase is being used referentially (i.e., to evoke or pick out a particular entity in the listener's discourse model), those modifiers serve to distinguish the noun phrases's intended referent from other entities in the model. (This last idea derives from Olson (1970).)

2.2 Sources of Antecedents and Referents

The role of inference in the scheme becomes clear as one considers how discourse entities can be evoked into the listener's discourse model. There are three such ways in which discourse entities can be evoked: (1) linguistically, from the explicit discourse; (2) perceptually, from the immediate spatio-temporal environment; and (3) inferentially, reasoning from the existence of particular other discourse entities. (Perceptual evocation of discourse entities is another way of looking at the "pragmatically controlled" definite pronouns discussed in Hankamer & Sag (1976).)

Inference also has a role in the formation of descriptions, in that the same three sources as above provide their raw material. The first source of descriptions is the discourse itself, with the language inducing particular ways of viewing and describing things. These things **may or may not** correspond then to entities in the listener's discourse model. Notice, for example, that after sentence (9) one would not presume any tie-dyed T-shirts to be in that model, since the original sentence is a negative assertion.

(9) Wendy didn't give either boy a tie-dyed T-shirt.

However, the existence of any referent is irrelevant to the description "tie-dyed T-shirt" being a possible antecedent for "one" in sentence (10).

(10) However, she did give Janet a red **one**.

The second source of descriptions is the external environment. As mentioned above, an entity may be evoked into the speaker or listener's discourse model as a result of what s/he **perceives**. How it is **described** will depend upon how s/he classifies that perception linguistically. As well as it can be presented on paper, the following is an example of a "one"-anaphor substituting for the speaker's description of some sense perception.

(11) [Bonnie goes up to a balloon man at the circus and says]
"Do you have a blue **one** with green stripes."
one = balloon

Again as with discourse entities, the third source of descriptions is inference. The speaker assumes the listener can and will follow the speaker's unspoken lead to infer:

1. from description d_1 of some entity in his or her discourse model, another description d_2 of that same entity;

2. from entities $e_1,\ldots,e_j$ with descriptions $d_1,\ldots,d_j$ respectively, a new discourse entity e_k with description d_k.

For instance, in sentence 6 of the introductory set of examples, the speaker assumes that the listener both can and will infer from the description "Ch. Figeac '71" another description for that same entity - namely "wine". Similarly for the descriptions "'76 Fleurie", "Ockfener Bockstein '75" and "Durkheimer Feuerberg '75". The "one"-anaphor then substitutes for the non-explicit shared description "wine".

In summary, inference can be a source of both non-explicit discourse entities and non-explicit descriptions, **provided that** the following **contract** between speaker and listener is maintained: if the speaker uses an anaphoric expression whose antecedent or referent was inferentially derived, s/he must have reason to believe that the listener both can and will make the same inference (even if only to resolve the anaphoric term). The problem now becomes one of either characterizing or enumerating such inferences.

The first thing to observe is that not all chains of reasoning will produce as side effects either new discourse entities or new descriptions. For example, consider the following as the first sentence of a discourse.

(12) You won't believe this, but I saw Wendy's mother at the Led Zeppelin movie last night, and **he** wasn't with her.

Who does the speaker presume the listener will identify as the referent of "he" in this example? It is clear that the text itself is no help. <*2>

<*2>. I unsuccessfully intended the pronoun to refer to Wendy's father. The point is that merely an "if mother, then father" axiom

$$(\forall x)[(Ey) \;.\; y = \text{mother-of}(x)] \Longrightarrow [(Ez) \;.\; z = \text{father-of}(x)]$$

i.e., "for any x, if there exists an individual who is x's mother, then there exists an individual who is x's father", true as it may be in the current world, is still not sufficient to yield a referent for "he" in sentence (12). That is, "he" cannot refer to Wendy's father solely by virtue of mentioning her mother.

The second thing to observe is that the range of inferences capable of providing referents for each type of deep anaphora will vary. For example, compare the following two examples: the first contains a definite pronoun, the second, an anaphoric definite description.

(13) Wendy ran into the kitchen and opened **it**. (14) Wendy ran into the kitchen and opened **the refrigerator**.

Here "the refrigerator" refers to the discourse entity describable as "the refrigerator in the just-mentioned kitchen that Wendy ran into". This entity, inferable by a highly salient and rarely false "if kitchen then refrigerator" axiom, is not accessible via the minimal cues of pronominal reference. (In Artificial Intelligence terms, the saliency of a collection of inferences is ensured by their being packaged together into a data-structure called a **frame, schema or script**. In this paper I shall only be concerned with inferences capable of providing antecedents and/or referents for pronominal or elliptic anaphora. For interesting discussions of anaphoric definite descriptions, see Bullwinkle (1977), Charniak (1973), Grosz (1977), Hobbs (1976) and Rieger (1974).)

Now unfortunately, there are no hard and fast rules which delimit the class of inferences which can evoke acceptable antecedents or referents for definite pronoun or "one"-anaphora. In general, the success of a particular inference in evoking a discourse entity or a description will depend on (1) its saliency in the particular context; (2) its contingency (i.e., how likely

it is to be valid in that context); and (3) the pressure of simultaneous demands on the listener's limited processing resources.

However, while I cannot characterize in terms of its defining properties the class of relevant inferences, I can list explicitly some very productive inferences which would have to be included in any account of non-explicit antecedents. While space limits me to presenting only three such inferences here, others can be found in Nash-Webber (1978). (In the following, I will present the axiom schemata used in "inferring antecedents and referents" in terms of a modified predicate calculus whose augmentations include the abstraction (or "lambda") operator (λ), the iota operator (ι) for forming definite descriptions, equality, restricted quantification and the set operator ({..}). To understand the factors motivating this choice of representation, see Nash-Webber(1978).)

2.3 Examples of Productive Inferences

Of the three inference schemata I shall discuss here, the first two can provide non-explicit antecedents and referents for definite pronouns, while the third provides antecedents for "one"-anaphora. The first inference schema (presented in a somewhat simplified form here) applies to existentially quantified propositions in cases where the existential quantifier has widest scope.

$$\underbrace{(Ex{:}\mathbf{A}) \,.\, Px}_{S_j} \Longrightarrow (Ey) \,.\, y = \iota z{:}\ \mathbf{A}z \,\&\, Pz \,\&\, \mathbf{evoke}\ S_j, z$$

i.e., informally, if a proposition S_j states that there is a member of class **A** for which **P** is true, then there exists an individual describable as "the **A** which **P**'s which was mentioned (or evoked) by S_j". Since a unique description can be ascribed to this individual, it can be referred to anaphorically with a definite pronoun. For example,

(15) a. Wendy ate an apple.
b. **It** had a worm inside.

Sentence 15a. can be represented simply as

(Ex:**Apple**) . **Ate** Wendy, x

Since this matches the left hand side of the above axiom schema, it follows that

(Ey) . y = ιz: **Apple** z & **Ate** Wendy,z & **evoke** S_{15a},z

i.e., there exists an individual describable as "the apple which Wendy ate which was mentioned in sentence 15a". The individual is the discourse entity referred to by "it" in sentence 15b. and the above definite description is its antecedent.

The second inference schema for definite pronouns applies whenever a non-negative sentence contains an existentially quantified noun phrase within the scope of a universal

$$(\forall x{:}A)(Ey{:}B) \,.\, P\ x,y \Longrightarrow (Ez) \,.\, z = \{w \mid Bw \,\&\, (Ex{:}\mathbf{A}) \,.\, \mathbf{P}\ x,w\}$$

i.e., informally, if for every **A** there exists a **B** such that **P** is true of the pair, then there exists an individual describable as "the set of B's for which there is some A that stands in relation

P to it". Since a unique description is ascribable to this individual, it can be referred to with a definite pronoun. For example,

(16)a. Each boy gave Wendy a shirt.
b. None of **them** fit.

Sentence 16a. can be represented simply as

(∀x:Boy)(Ey:Shirt) . Gave x,Wendy,y

Since this matches the left-hand side of the second axiom schema, it follows that

(Ez) . z = {w|**Shirt** w & (Ex:**Boy**) . **Gave** x,Wendy,w}

i.e., there exists an individual describable as "the set of shirts, each of which some boy gave to Wendy". This is the discourse entity referred to as "they" in example 16b.

The third inference schema I will discuss produces non-explicit antecedents for "one"-anaphora. Consider example (6), repeated here:

(6) I have a '71 Ch. Figeac, a '76 Fleurie, a '71 Ockfener Bockstein and a '75 Durkheimer Feuerberg in the cellar. Shall we have the German **ones** for dinner?

In this example, the speaker has turned an **explicit** set description (i.e., the presented list) into an **implicit** set description (i.e., one based on a defining property) and then used the latter description as an antecedent for "one"-anaphora. In doing so, the speaker presumes the listener is both able and willing to do the same. (That is, the speaker appeals to the "inference contract" mentioned in the previous section.) The unanswered question is why such an inference from explicit to

implicit set description should occur and moreover be predictable. <*3>

3. Inference and Surface Anaphora

"Surface anaphors" are so called because they are seen to be purely surface phenomena. The primary condition for a successful surface anaphor-antecedent pair (cf. Hankamer & Sag (1976) and Sag (1976)) is that the antecedent forms a coherent structural unit at the level of surface syntax or the level of logical form (subject to some type of Backward Anaphor Constraint). However, that condition is not fulfilled in the following examples which illustrate different types of surface anaphora.

Sluicing

(18) Wendy is going to Spain and Bruce is going to Crete, but in neither case do I know why Ø.
Ø = that person is going where s/he is going

"Do so" Anaphora

(19) Wendy's car was repaired today by the same guy who had **done so** last week. (after Kaplan (1976))
do so = repair Wendy's car

Verb Phrase Ellipsis

(20) I can walk and I can chew gum. Ford can Ø too, but not at the same time.
Ø = walk and chew gum

<*3>. One might note in passing that the first two inference schemata depend solely on the **form** of an utterance, while this third one depends on its **content** as well. Thus world knowledge can be seen to play a part (although, I would argue, a small one) in **deriving** possible antecedents as well as in **choosing** between them.

(21) China is a country that Nixon wants to visit, and he will Ø too, if he gets an invitation soon.
Ø = visit China

The problem is that of accounting for such exceptions to the above constraint on surface anaphor-antecedent pairs. One way to do so is to again invoke inference. In the remainder of this section, I shall first sketch, albeit briefly, an approach to verb phrase ellipsis based on identity of predication at the level of logical form. I shall then argue that inference can play a part in deriving additional logical forms whose predicates can serve as antecedents for ellipsed verb phrases. I shall illustrate this claim with two examples. Others can be found in Nash-Webber (1978).

Now if examples such as those above are ignored, the approach to verb phrase ellipsis (or "verb phrase deletion" - VPD) presented in Sag (1976a&b) provides an adequate account. Sag's thesis is that verb phrase ellipsis is conditioned by identical predicates (rather than by identical VPs or identical substrings) in a logical form representation of the two clauses involved. (Identity here is determined modulo differences in the names of bound variables, i.e., "alphabetic variance".) This logical form representation makes essential use of the lambda operator both to bind variables and to form complex predicates which may themselves contain quantifiers and logical connectives. For example, Sag (1976a) assigns the sentence "John scratched his arm" the two logical form representations

a. $John_i$, $\lambda(x)$(x scratched his_i arm)
b. $John_i$, $\lambda(x)$(x scratched x's arm)

That there are two possible logical forms for this sentence explains the ambiguity to be found in a subsequent ellipsed verb phrase sentence like

Fred did ∅ too.

(Did what? Scratched his own arm or scratched John's?) Sag claims that

> With respect to a sentence S, VPD can delete any VP in S whose representation at the level of logical form is a lambda-expression that is an alphabetic variant of another lambda-expression present in the logical form of S or in the logical form of some other sentence S' which precedes S in the discourse. (Sag 1976a)

In short, Sag shows that by looking at sentences in terms of the predicate-argument relations they express, a clean account can be given of verb phrase ellipsis (barring for now the initial set of examples). This in turn gives credence to the psychological reality of some type of "logical representation" within the dual processes of text generation and comprehension.

But if the process of forming a logical representation is part of the normal process of understanding discourse, then it is possible that **alternative** ways of understanding a sentence or sequence of sentences or even valid, salient **implications** of sentences may also provide lambda-predicates for verb phrase ellipsis. And this is the point I want to stress: whereas Hankamer & Sag's condition implies a very **static** view of verb phrase ellipsis and other surface anaphora, the above

process-oriented view suggests that a more **plastic** approach is justified. The proviso seems to be that the **form** of expression of the derived proposition does not differ radically from the form of those explicitly given.

Now "alternative ways of understanding" and "valid implications" are both notions which involve inference. But not every valid inference provides lambda-predicates accessible to verb phrase ellipsis. For example, the following axiom relates the notions of "selling" and "being bought".

$$(\forall x)(\forall y)(\forall z)\ .\ x,\ \lambda(r)[r \text{ sold } y \text{ to } z] \Longrightarrow y,\ \lambda(s)[s \text{ was bought by } z]$$

i.e., if any x sold any y to any z, then y was bought by z". <*4> Notice that this axiom is not sufficient to produce a predicate "was bought by z", given an explicit predicate "sold y to z" --

(22) Bruce sold a waffle iron to Wendy, and an electric wok was ∅ too.
∅ ≠ bought by Wendy

Unfortunately, aside from the caveat that the logical forms of both the overt sentence(s) and the derived one be "similar" in some undefined sense, there are no hard and fast rules delimiting the class of productive inferences relative to verb phrase ellipsis. What I shall do in the space remaining then is to set down two inference schemata which account for the two problematic

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<*4>. For the remainder of this paper, I will be following Sag's intuitively clear conventions (Sag 1976a&b) for writing logical forms. However, for computational purposes at least, a more rigorous formalism is called for (cf. Nash-Webber (1978)).

examples of verb phrase ellipsis presented above (examples 20) and 21).

The first inference schema is applicable to a sequence of propositions with identical subjects and auxiliaries: its effect is to abstract a new predicate off of the common argument.

y, AUX(λ(r)[P r]) & y, AUX(λ(s)[Q s]) ==>
y, AUX(λ(t)[P t & Q t])

AUX, the sentence auxiliary, is interpreted as an operator on predicates, although up to now it has been omitted for simplicity. Informally, this schema says that if y P's and y Q's, then y P's and Q's. The propositions on either side of the implication, while structurally different, are semantically equivalent (at least with respect to an extensional semantics).

To illustrate the application of this inference schema, reconsider example (20), repeated below.

(20)a. I can walk and I can chew gum.
b. Jerry can ∅ too, but not at the same time.

Sentence (20a) can be represented as <*5>

I, CAN(λ(r)[r walk]) & I, CAN(λ(s)[s chew gum])

Since this matches the left-hand side of the above rule schema, it follows that

I, Can(λ(t)[t walk & t chew gum])

This has as a constituent the lambda predicate

<*5>. This is actually a simplification of the procedure I follow throughout Nash-Webber (1978), but the essential ideas are the same.

λ(t)[t walk & t chew gum]

i.e., "walk and chew gum", which is intuitively the correct antecedent for the ellipsed verb phrase in sentence (20b). <*6>

The second rule schema I will discuss here applies to statements of restricted class membership. Its effect is to derive a new proposition expressing the restriction alone, whose lambda predicate is accessible to verb phrase ellipsis. Since I do not have the space here to motivate the notation I need to express this rule schema formally, I will express it informally as

<x> is a <B> which <y> <C>s ==> <y> <C>s <x>

where <B> is a class description (e.g., elephant, snowmobile, etc.) and <C> is a verb phrase whose subject is <y>. To illustrate the application of this rule schema, reconsider example (21), repeated below.

(21) China is a country that Nixon wants to visit, and he will ∅ too, if he gets an invitation soon.

Proceeding informally, the first clause of (21) matches the left-hand side of the above rule schema. It therefore follows that

---

<*6>. The reason for requiring the conjuncts to have identical auxiliaries is the strangeness of those examples in which they do not. For example,

Bruce attended Harvard, and now he is going to MIT.
Fred {did, does, will, is} ∅ too.

"Fred did ∅ too" seems to imply only that he attended Harvard. "Fred is ∅ too" seems to imply only that he is now going to MIT. The other auxiliaries just seem bizarre. The sense that Fred also attended Harvard and is now going to MIT does not seem to be conveyable using an ellipsed verb phrase.

Nixon wants to visit China

i.e., using Sag's notation for lambda predicates,

Nixon, λ(r)[r wants [r, λ(s)[s visit China]]]

This has as a constituent the lambda predicate

λ(s)[s visit China]

which intuitively is the intended antecedent of the ellipsed verb phrase in the second clause of (21).

4. Conclusion

In this paper, I have discussed the concept of inference as a factor in the derivation of non-explicit antecedents and referents for discourse anaphora of both deep and surface varieties. I have shown how inference schemata can be applied to a formal representation of the discourse to produce additional formulae which suggest, through their structure, possible antecedents and referents. I have tried to motivate this as part of the normal process of text-understanding. I have claimed the use of non-explicit antecedents and referents for anaphoric terms depends on a contract between speaker and listener. This contract stipulates that if the former uses an anaphoric expression whose antecedent or referent was inferentially derived, the latter both can and will make the same inference. Insofar as many of these inferences rely on one of the few things **explicitly** available to both speaker and listener - i.e., the **form** of the utterance - the search for productive inferences vis a vis discourse anaphora is a matter of linguistic concern.

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